NASA CONTRACTOR REPORT 166356

Development of a Silicon BIB Infrared Detector Array

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Rockwell International Science Center

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Development of a Silicon BIB Infrared Detector Array

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

Rockwell International's Science Center has developed a new long wave infrared (LWIR) detector concept. Designated as Blocked Impurity Band (BIB) detectors, these devices offer the following known advantages over conventional extrinsic silicon photoconductive (ESPC) detectors:

1. Freedom from such irregularities as memory effects, pulse shape variations, nonlinear responsivity, and nuclear-induced responsivity variations

2. Fast photoresponse

3. Better array uniformity

4. Low optical crosstalk

5. Extended cutoff wavelength (~15% longer than conventional detectors).

6. Increased nuclear hardness (less nuclear-induced noise).

Because of their high responsivity coupled with good array uniformity, low optical crosstalk, and freedom from performance irregularities, BIB detectors offer significant benefits for several applications.

In this program, each detector of a ten-element linear BIB detector array was connected to a load resistor and JFET preamplifier and mounted on a gold-plated copper heatsink. The array can be operated in either the transimpedence (feedback) amplifier or source follower mode. Tests were performed which confirm some of the advantages of BIB detectors over ESPC detectors.

2.0 DESCRIPTION OF BIB DETECTOR ARRAY

2.1 The BIB Concept

Blocked Impurity Band (BIB) detectors were conceived, modeled, designed, and fabricated at Rockwell International. An arsenic-doped silicon BIB detector, with a structure shown in Figure 1, was selected for this contract. The BIB concept is not dependent on this particular configuration nor is it dependent on the choice of arsenic-doped silicon as the IR-active material. The device shown in Figure 1 consists of two epitaxial layers deposited on a degenerately-doped silicon substrate. The first of these layers is a heavily (although not degenerately) arsenic-doped IR-active layer, the second is an intrinsic blocking layer. A shallow n^+ ion implant over sections of the blocking layer provides a transparent contact and defines the detector area. The device is intended for operation at temperatures where thermal generation of free carriers is negligible.

The IR-active layer in a silicon BIB detector is doped to a level more than an order of magnitude higher than has been found to be practical for a conventional silicon photoconductor. Better than a tenfold reduction in thickness is thus achieved without sacrificing quantum efficiency or responsivity. This reduction in thickness leads directly to the advantages of increased radiation hardness and reduced crosstalk in focal plane arrays of BIB detectors.

The focal plane assembly for this contract includes a ten-element BIB detector linear array along with a load resistor and JFET preamplifier for each array element. Also included on the array chip is a large area test BIB (BIB #5) detector. All components were mounted on a gold-plated copper heatsink.

2.2 Heatsink Design and Fabrication

A heatsink was designed and fabricated from copper to accommodate the preamplifier packages, load resistors, and the BIB detector array. It provides a mechanical base for all the components and also fulfills the thermal and electrical requirements. The heatsink was thermally cycled and found to effectively maintain the required low temperature of the assembly while dissipating the heat from the operating JFETs. One JFET preamplifier uses 200 to 300 microwatts of power in the form of heat which had to be transmitted by the heatsink for dissipation in the liquid helium stored in the dewar.

In order to minimize microphonic noise, it was desirable to have the lead length connecting the JFET gate, load resistor, and BIB detector as short as possible. The components are arranged on the heatsink in such a manner as to achieve this goal. The heatsink and array assembly are shown schematically in Figure 2.

2.3 Array Selection

Rockwell has fabricated both arsenic- and gallium-doped BIB detectors. DC photoresponse and dark current were measured on BIB detectors from several silicon wafers using funds from a company-funded program. Based on these test results and other performance tests by the Naval Ocean Systems Center, San Diego, California, one arsenic-doped (Si:As) wafer was singled out as having devices with excellent performance.

Five ten-element BIB detector arrays were selected from the chosen wafer. They were packaged for cryogenic tests in 42-pin flatpacks using conductive epoxy. Two of the packaged ten-element BIB detector arrays underwent dc screening at cryogenic temperatures. Current vs voltage was measured at 10°K for each array element and BIB #5 using the test setup shown in Figure 3. Bias voltage was applied to the transparent contact of each element with respect to the device substrate while all other elements were floating. The arrays exhibited good IR response, a high degree of uniformity, and low dark current. Photoresponse scaled to the area ratio between BIB #5 and an array detector. Leakage current was measured between transparent contacts of adjacent elements while all other points of the array were floating and was found to be less than 10^{-13} A at 1.0V bias. Based on the above test results, an array was selected to be mounted on the heatsink and connected to the JFET preamplifiers for ac testing. Data for the chosen array is shown in Figures 4-17. Apparent negative resistance at low bias in Figures 15-17 is due to instrumentation and is not a characteristic of the device.

2.4 JFET Operation

Two five-channel JFET preamplifier packages were received from NASA. The supplier of the JFET modules was Infrared Laboratories, Tucson, Arizona. Each channel is comprised of a selected matched pair of JFETs as described in the Appendix. The Appendix is a reprint of information supplied by Infrared Laboratories.

The JFETs are supposed to be self-heated for automatic startup at 4°K. However, after the JFETs were stored at 4.3°K, with power off, for approximately 30 minutes, we were unable to restart them.

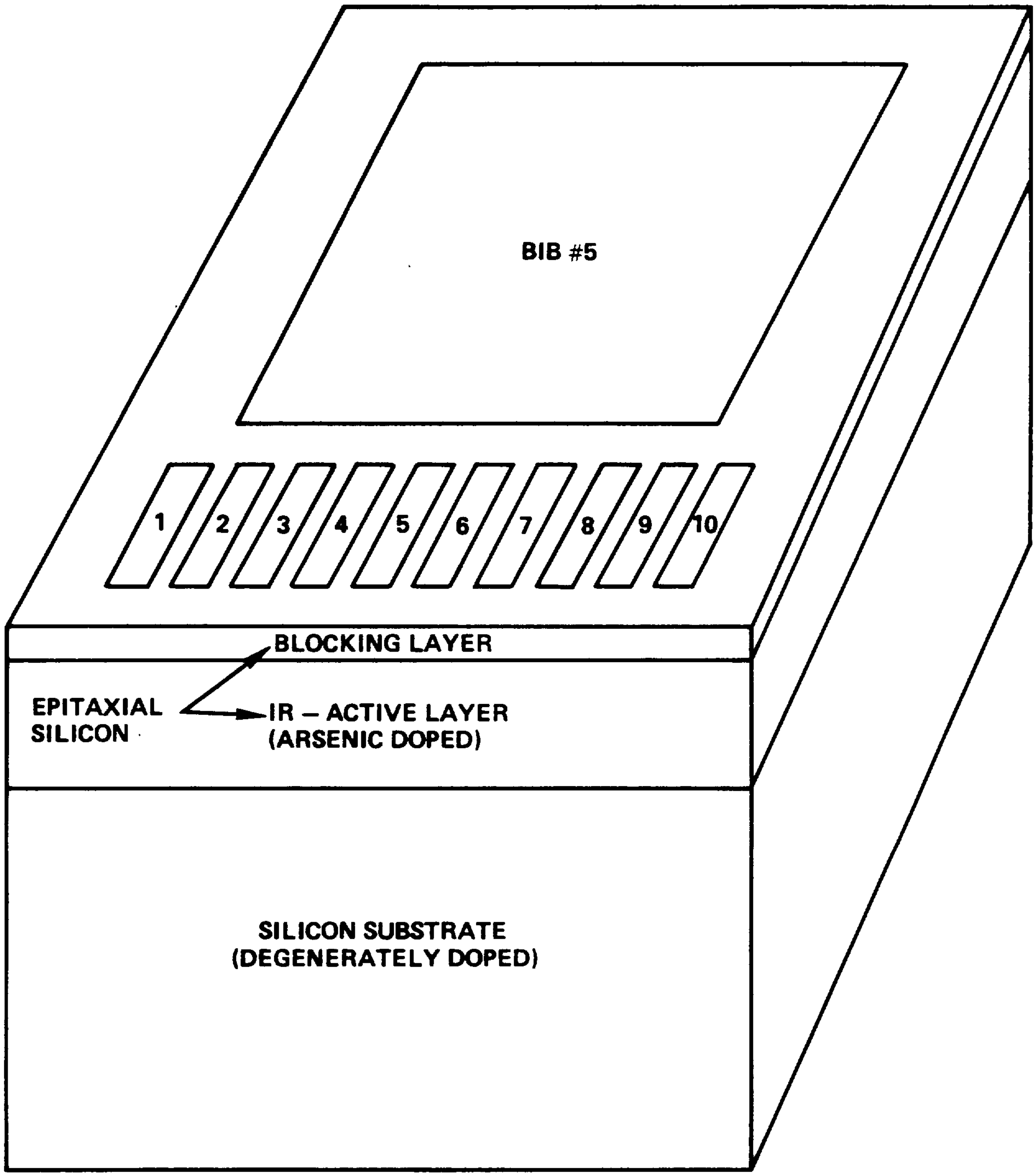

FIGURE 1. BIB DETECTOR CONFIGURATION

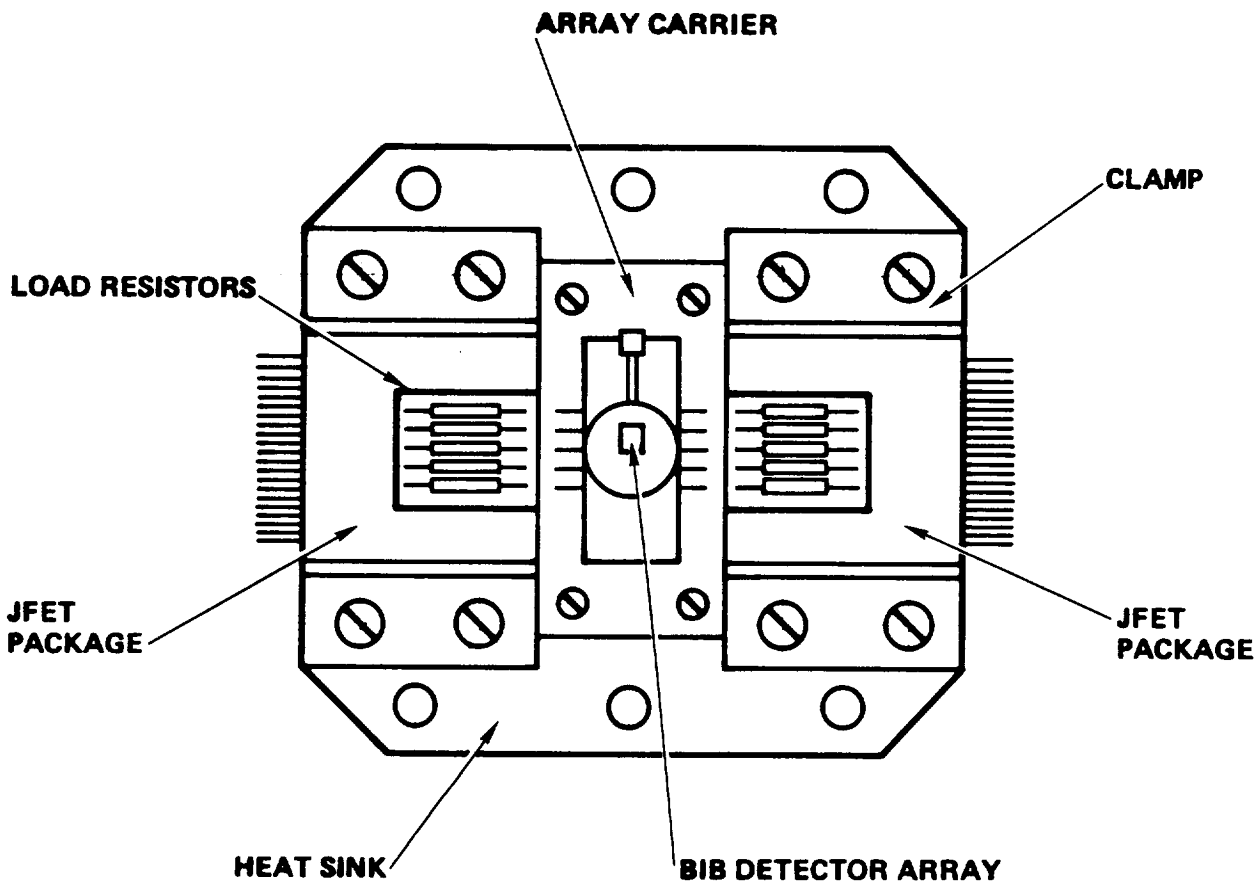

FIGURE 2. HEATSINK AND ARRAY ASSEMBLY

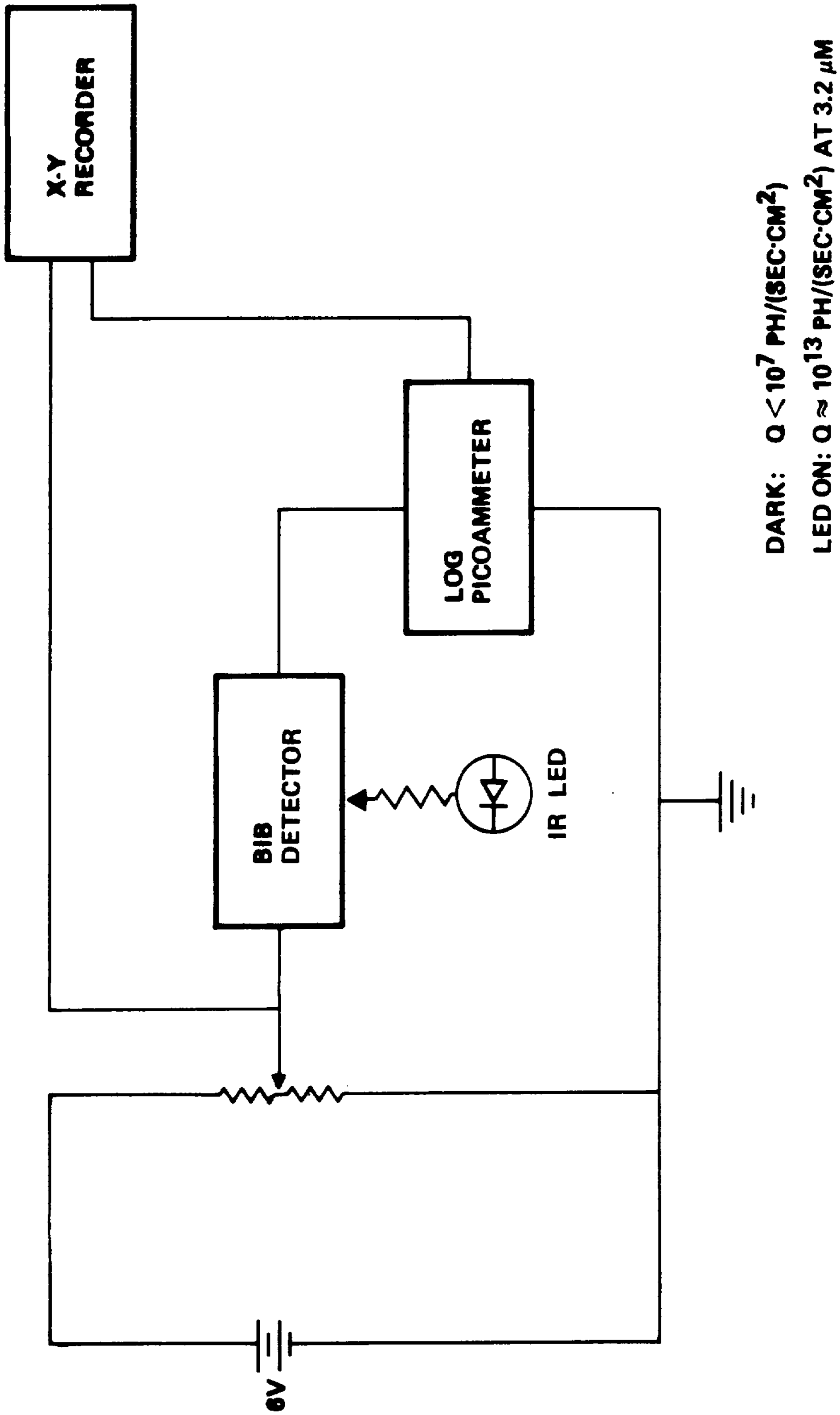

FIGURE 3. DC I-V MEASUREMENT SETUP

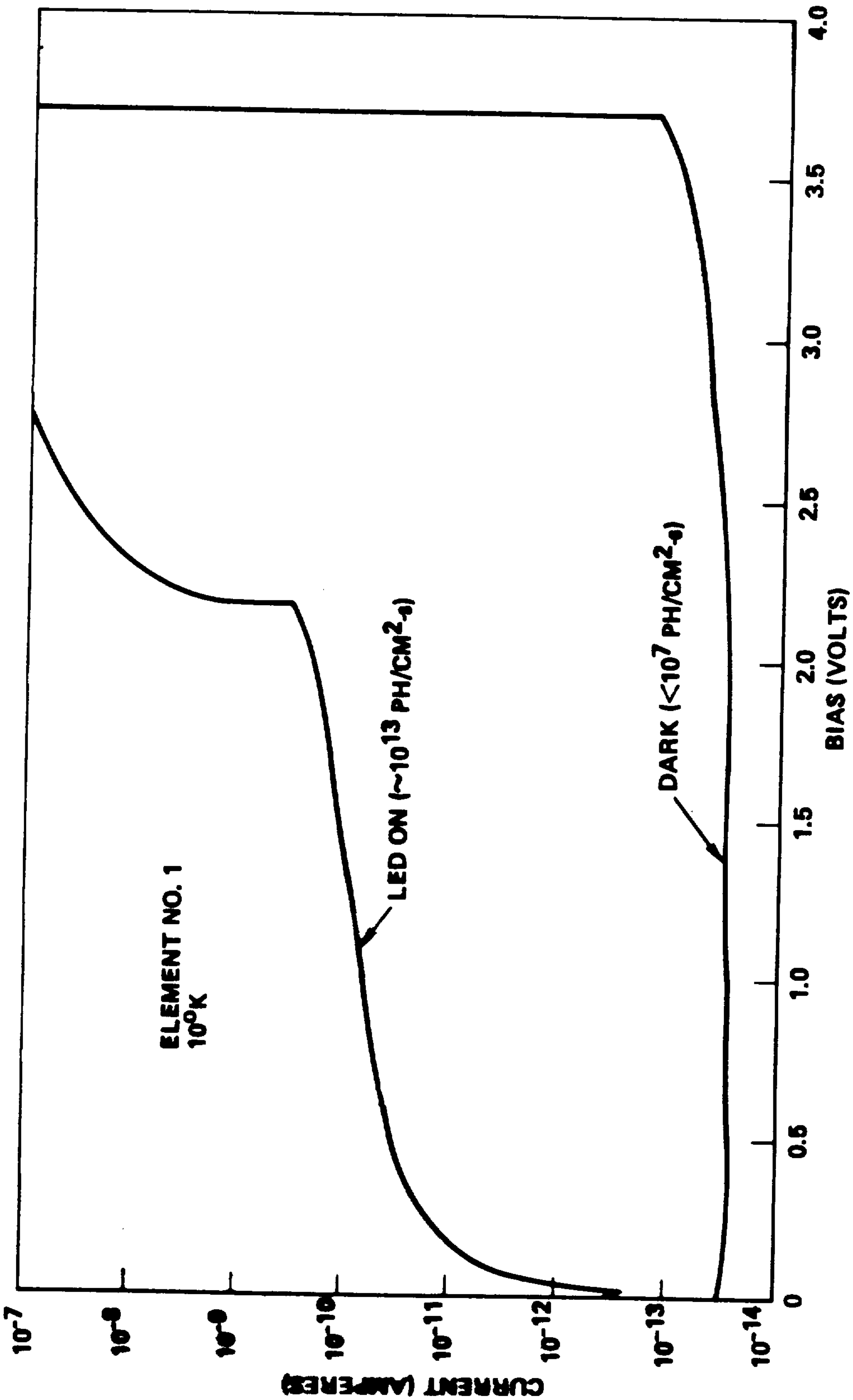

FIGURE 4. DC I-V CHARACTERISTIC: ELEMENT #1

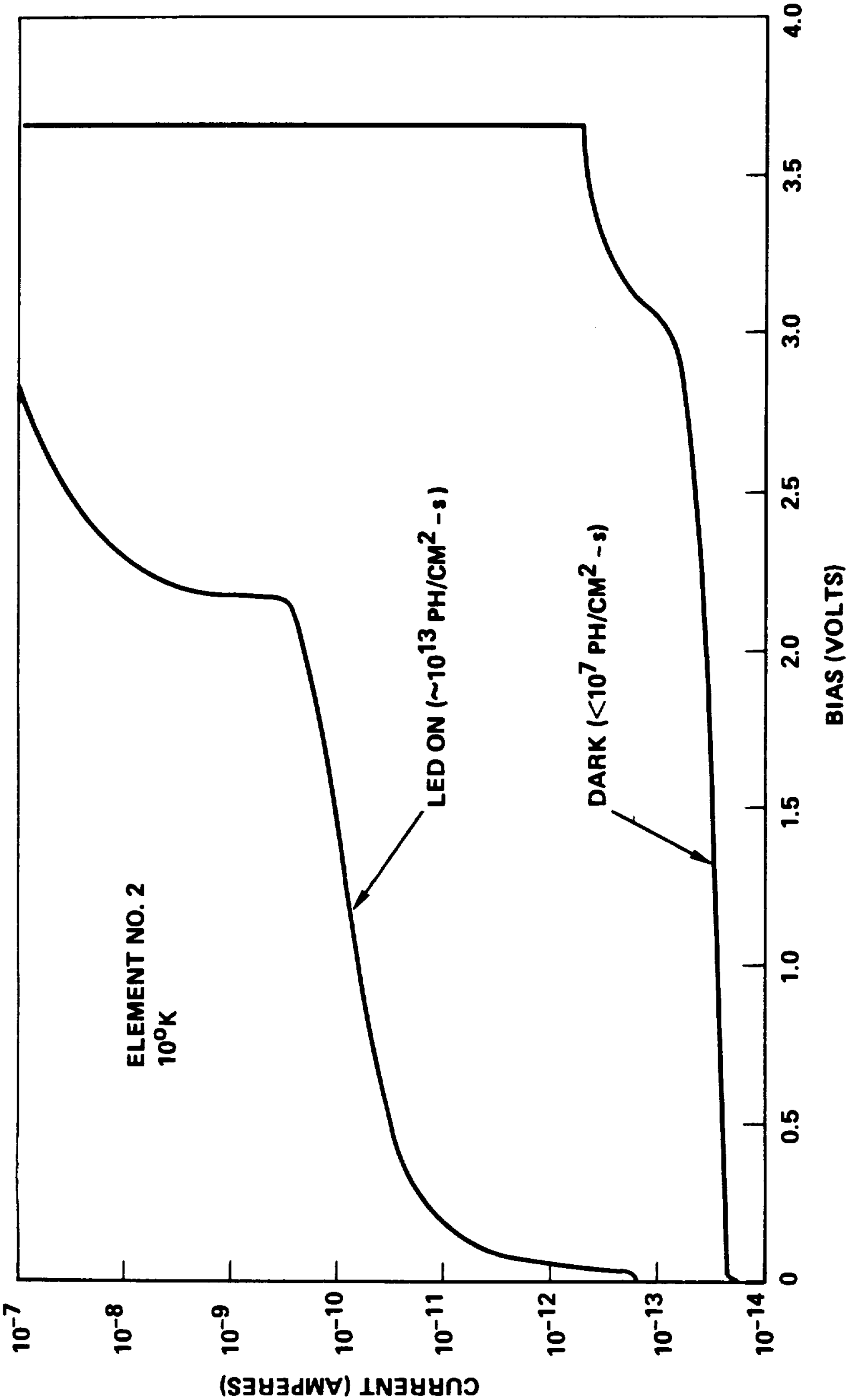

FIGURE 5. DC I-V CHARACTERISTIC: ELEMENT #2

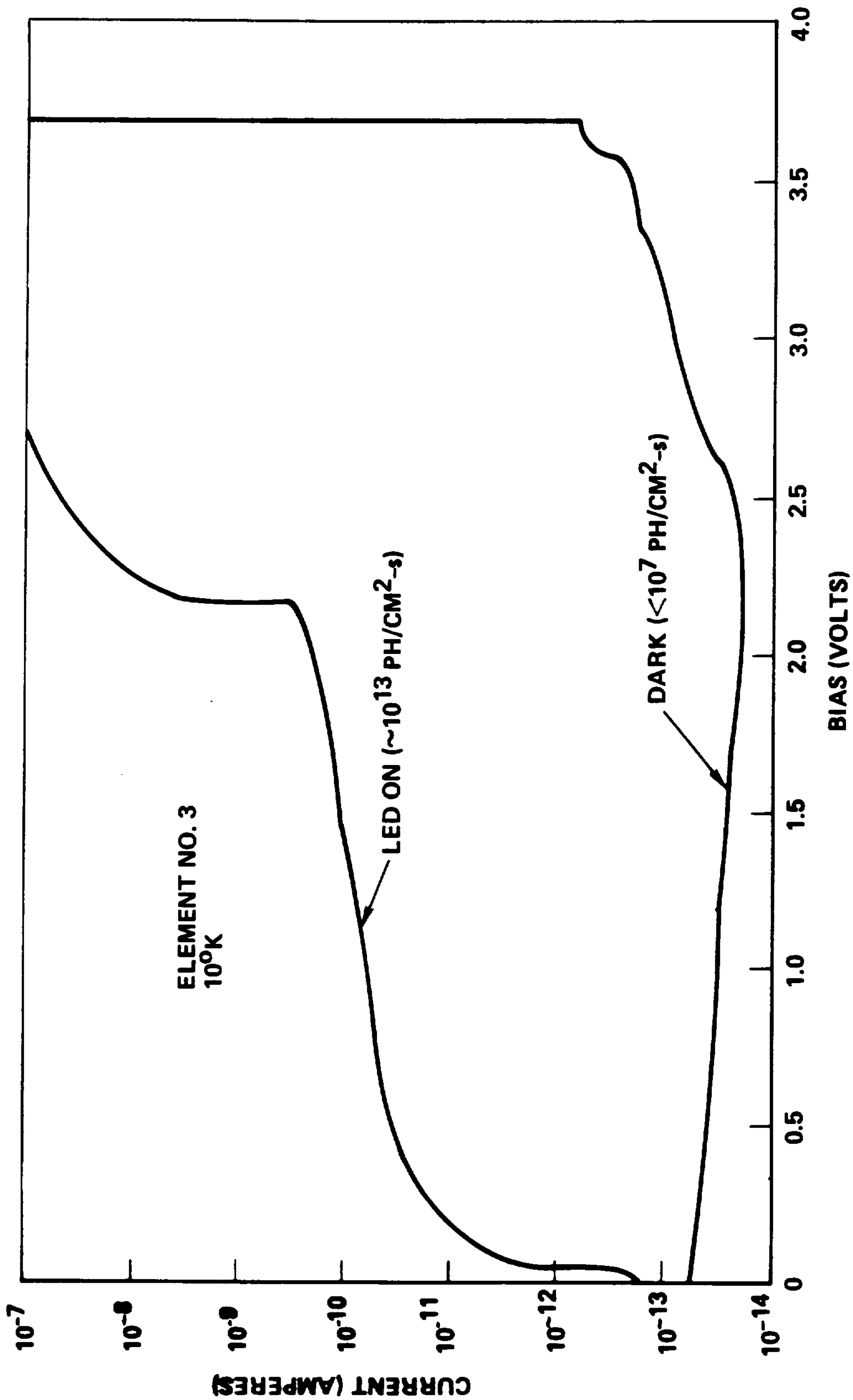

FIGURE 6. DC I-V CHARACTERISTIC: ELEMENT #3

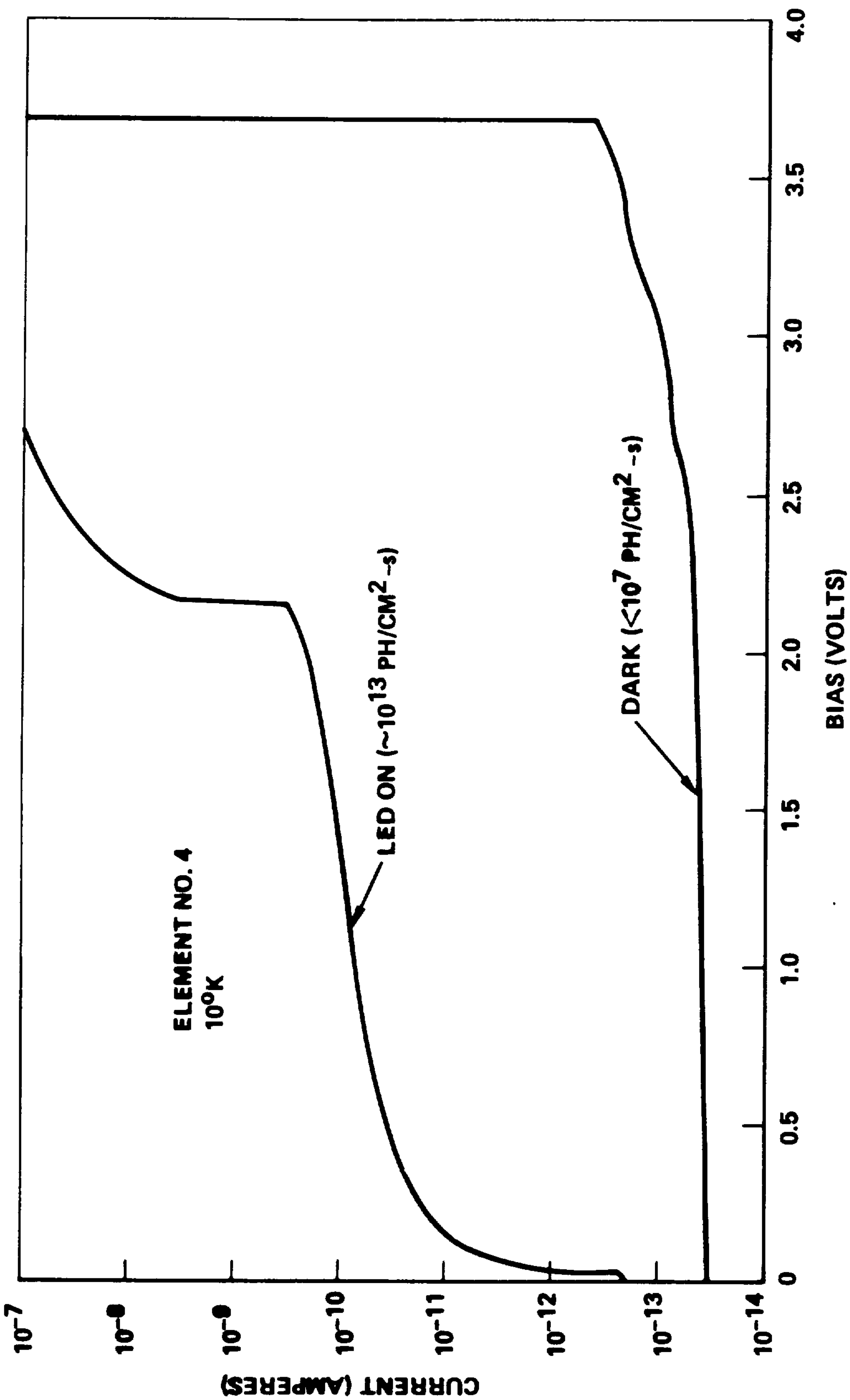

FIGURE 7. DC I-V CHARACTERISTIC: ELEMENT #4

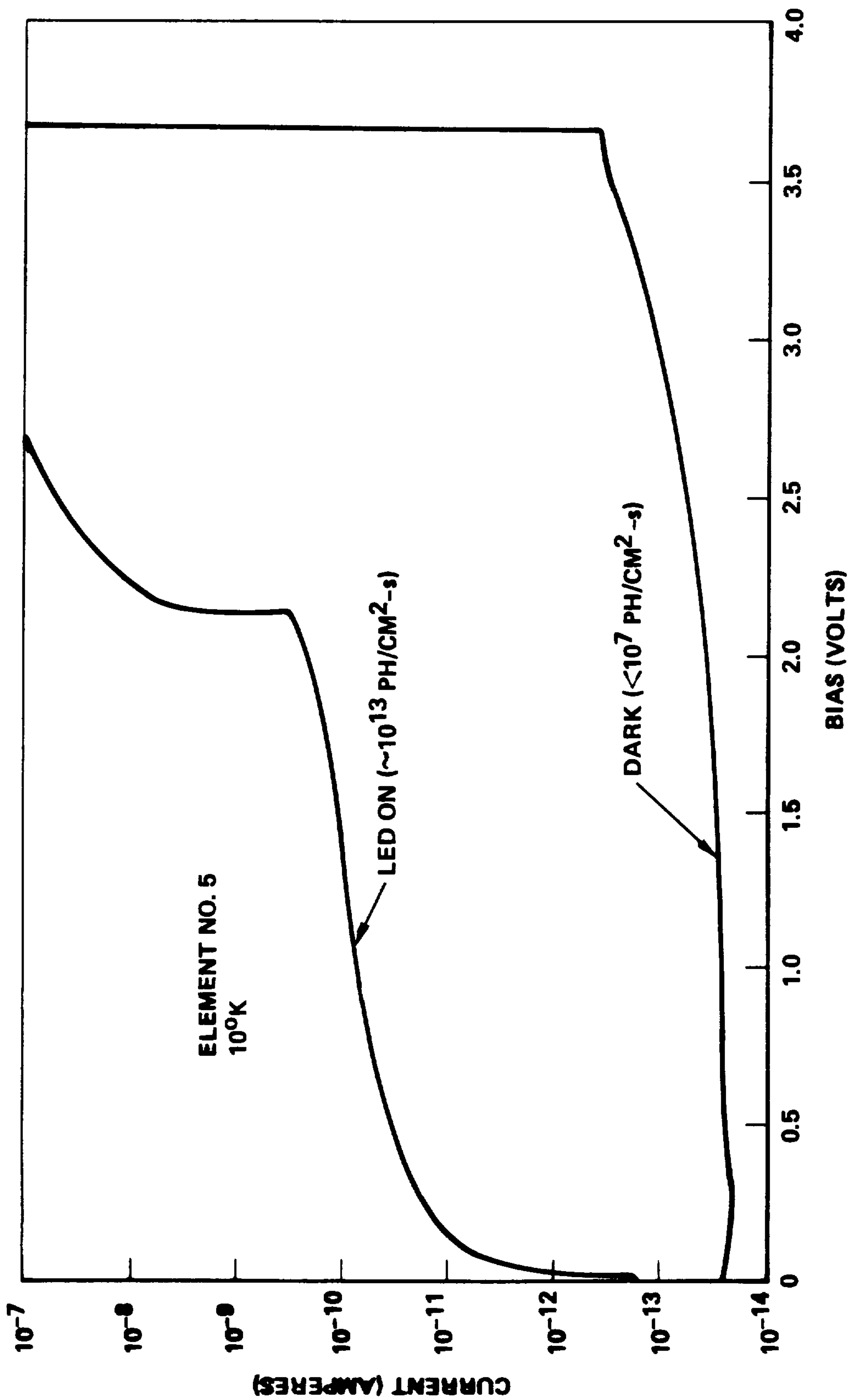

FIGURE 8. DC I-V CHARACTERISTIC: ELEMENT #5

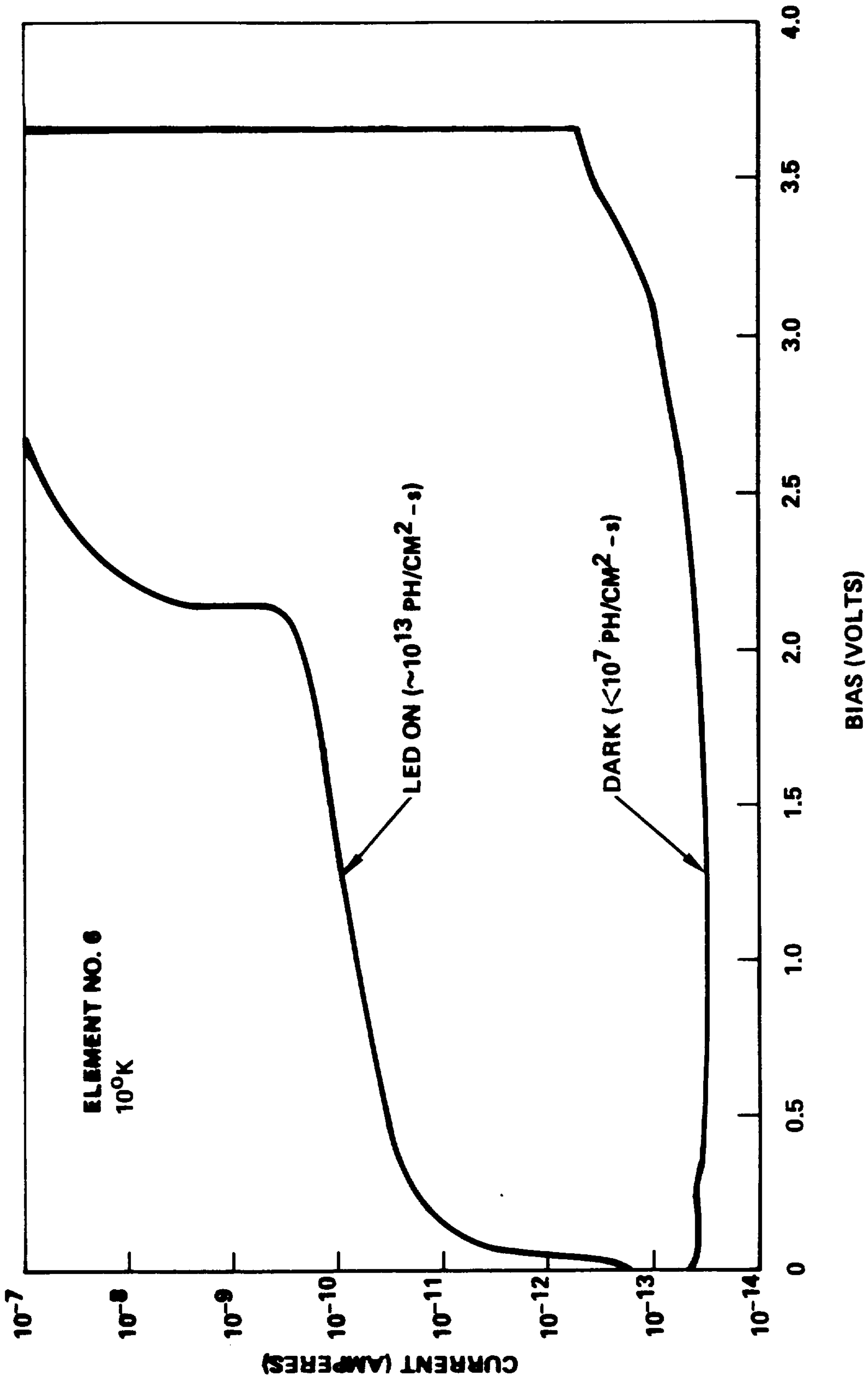

FIGURE 9. DC I-V CHARACTERISTIC: ELEMENT #6

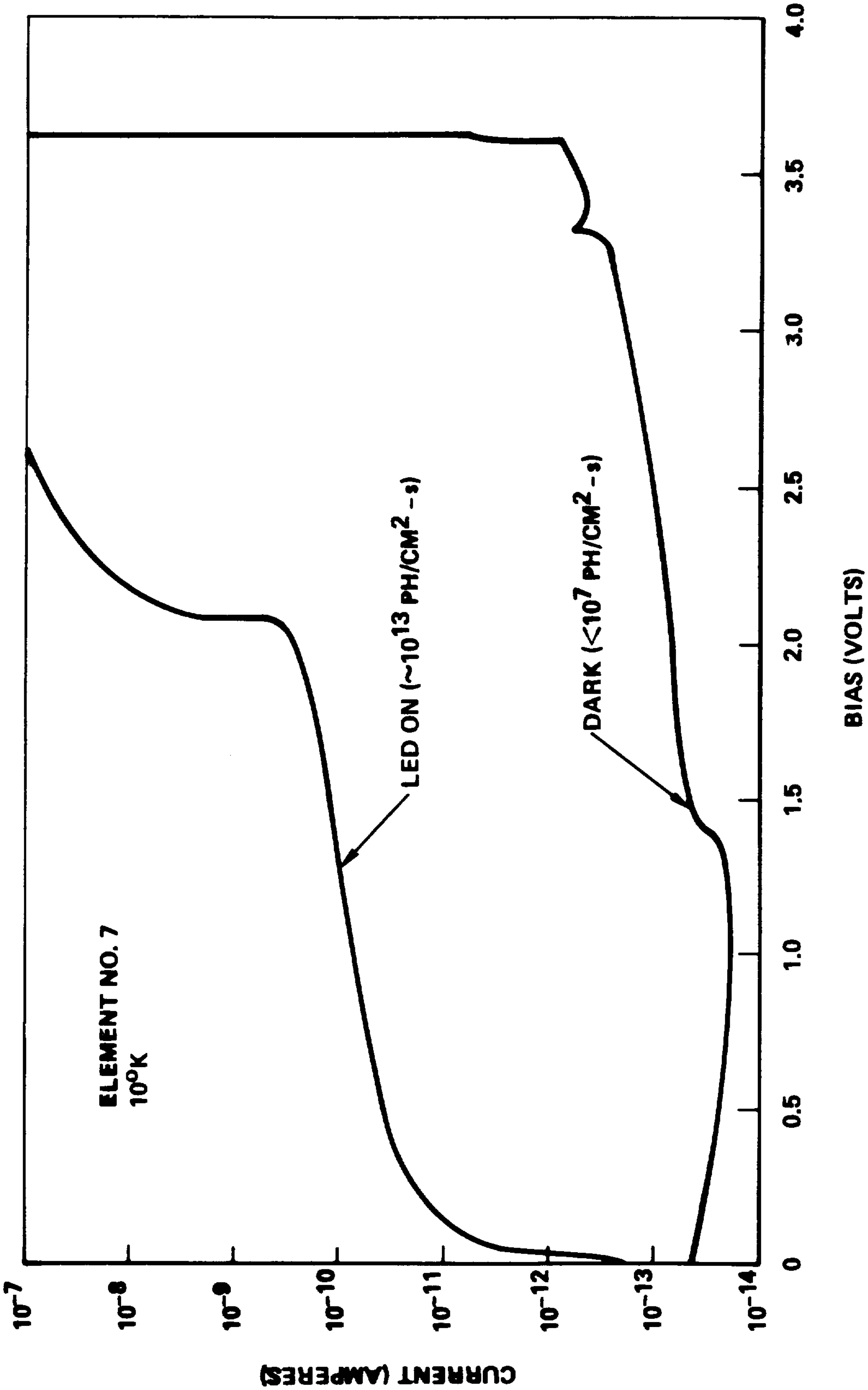

FIGURE 10. DC I-V CHARACTERISTIC: ELEMENT #7

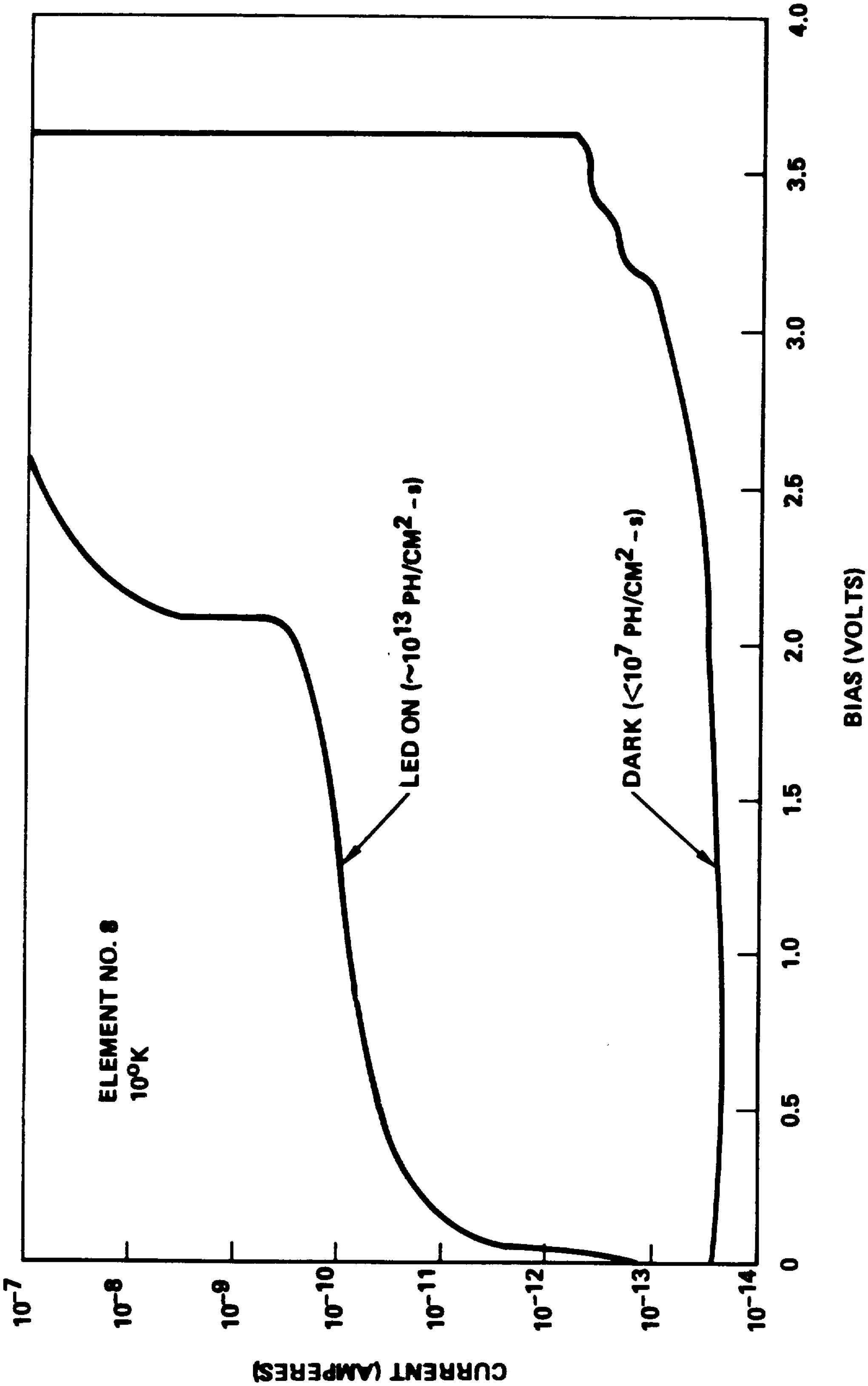

FIGURE 11. DC I-V CHARACTERISTIC: ELEMENT #8

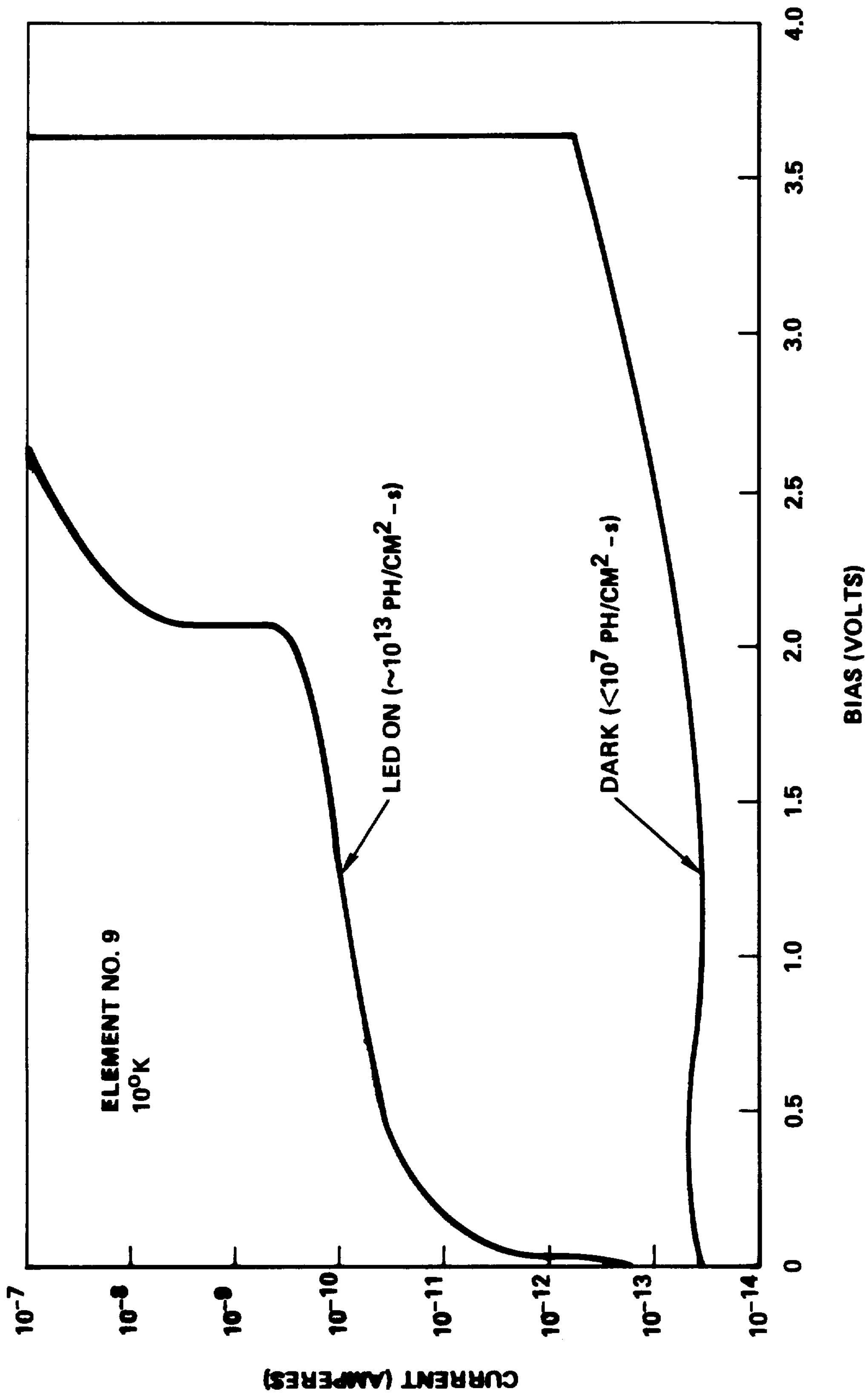

FIGURE 12. DC I-V CHARACTERISTIC: ELEMENT #9

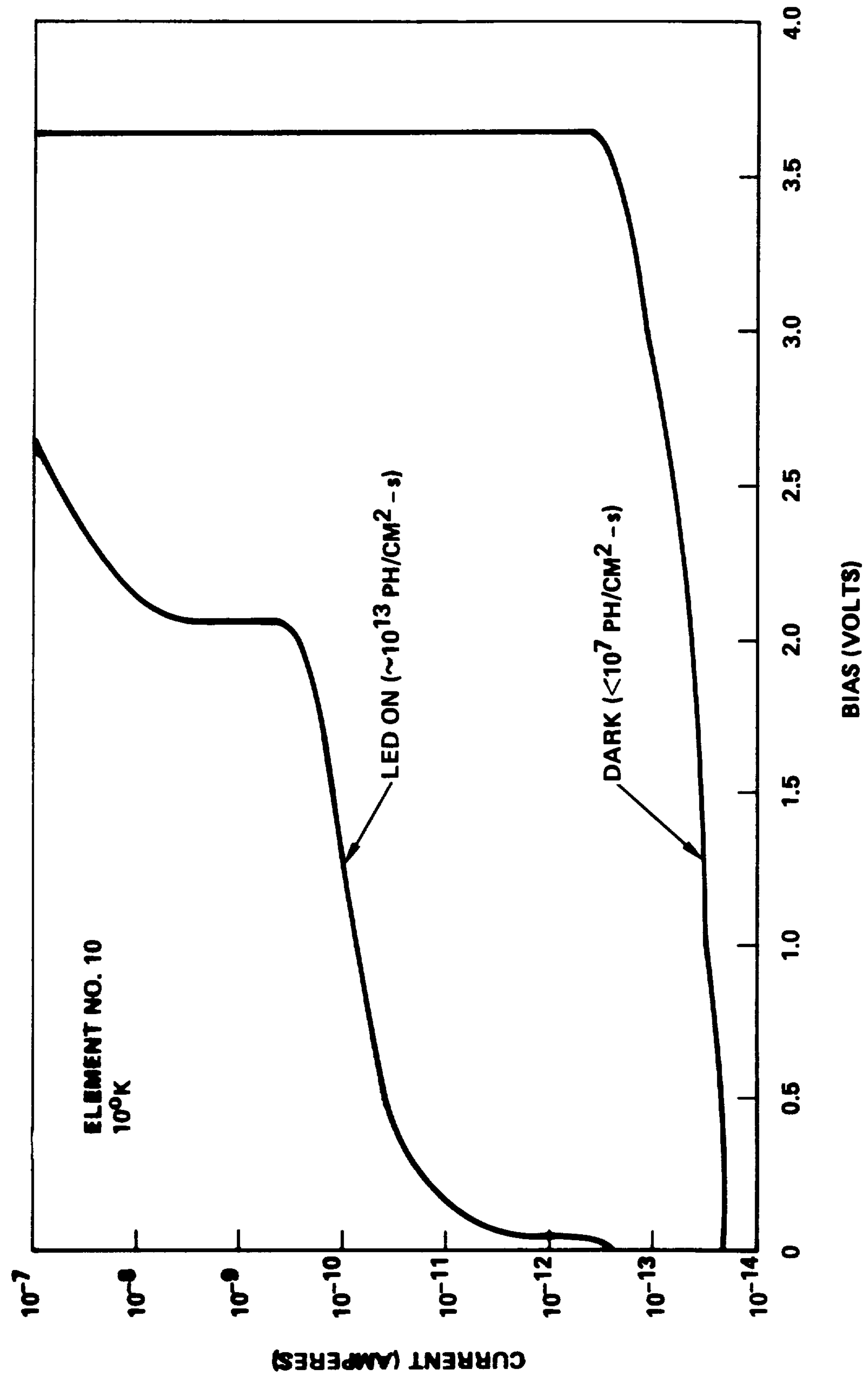

FIGURE 13. DC I-V CHARACTERISTIC: ELEMENT #10

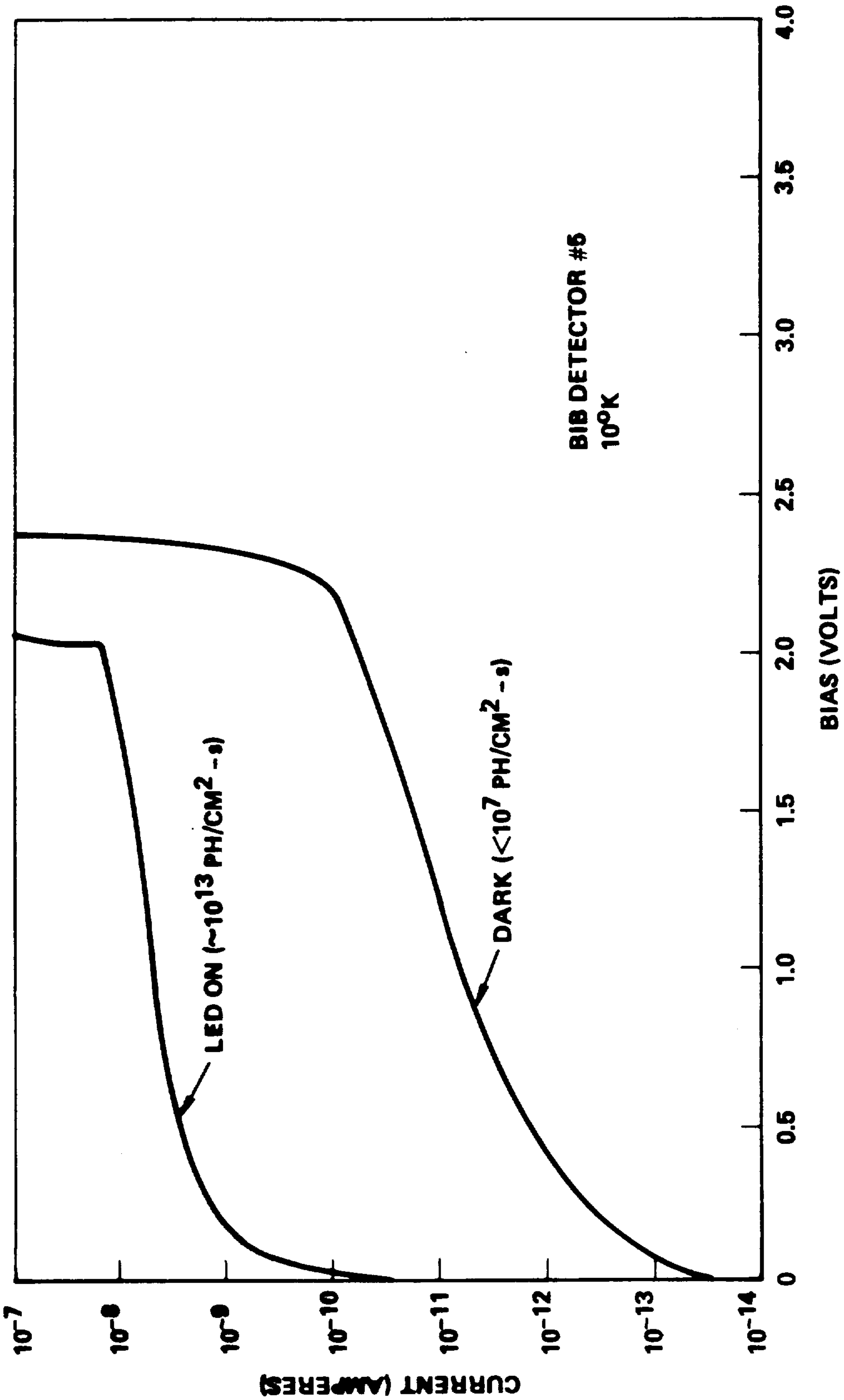

FIGURE 14. DC I-V CHARACTERISTIC: BIB #5

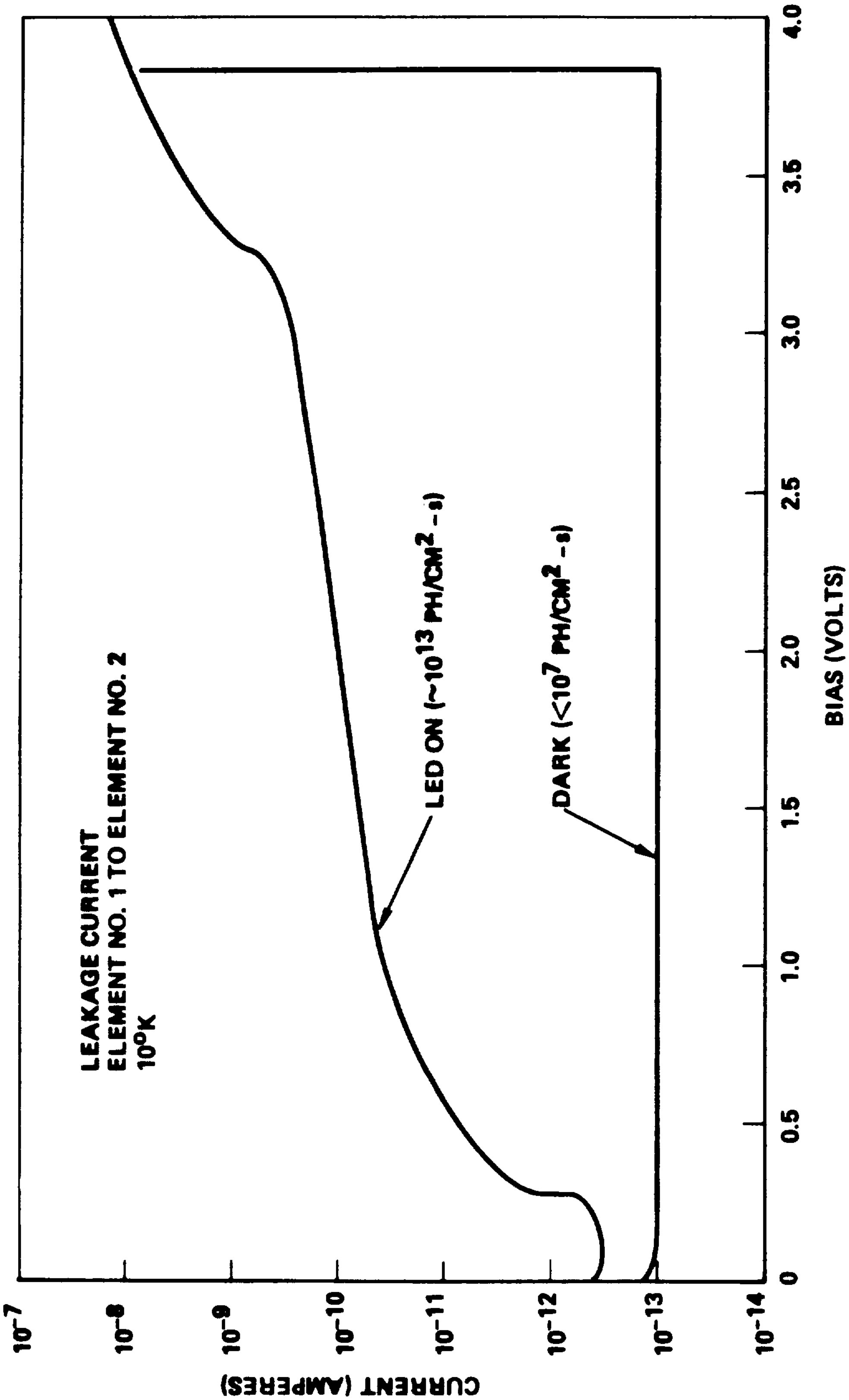

FIGURE 15. DC LEAKAGE CURRENT: ELEMENT #1 TO #2

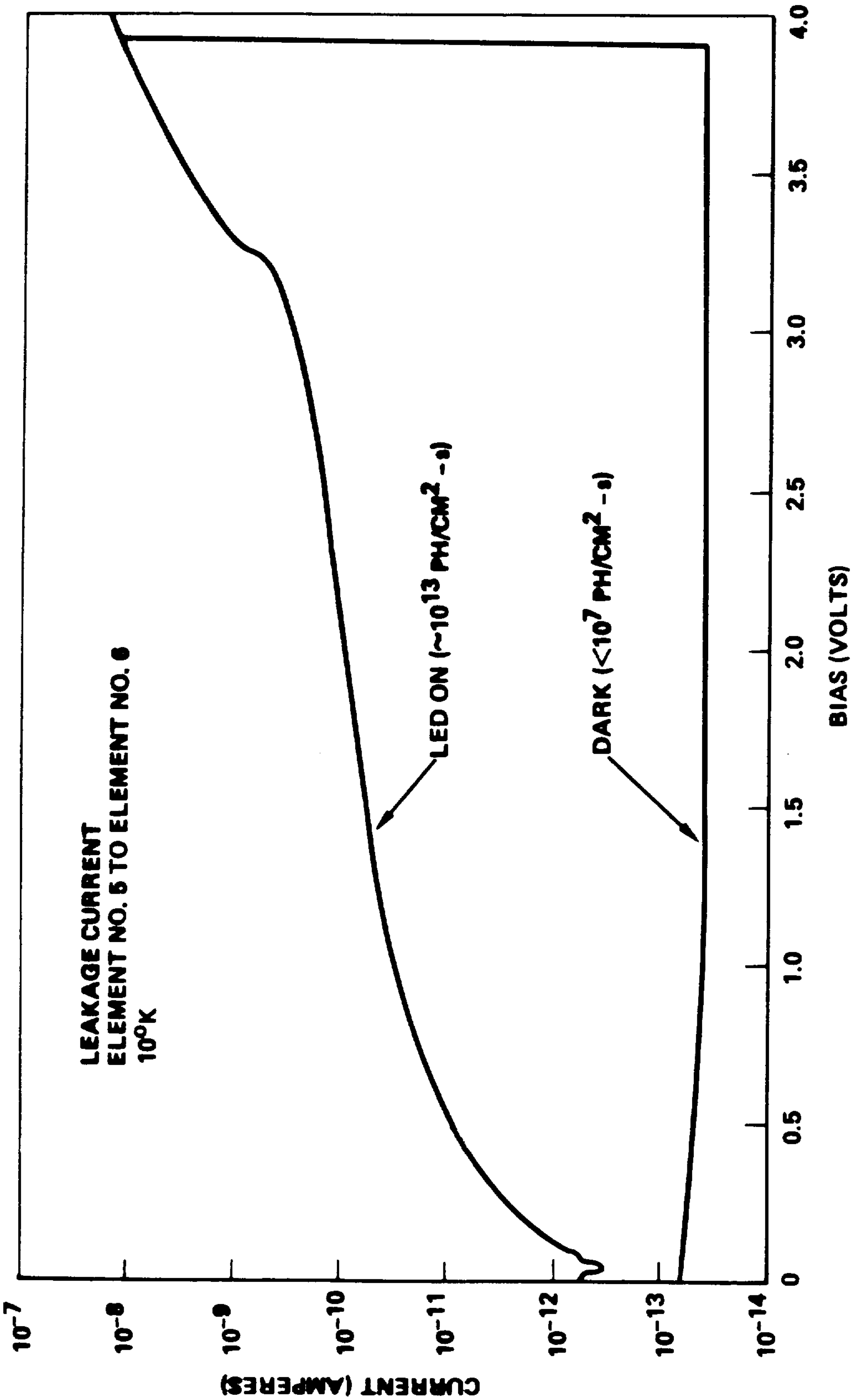

FIGURE 16. DC LEAKAGE CURRENT: ELEMENT #5 TO #6

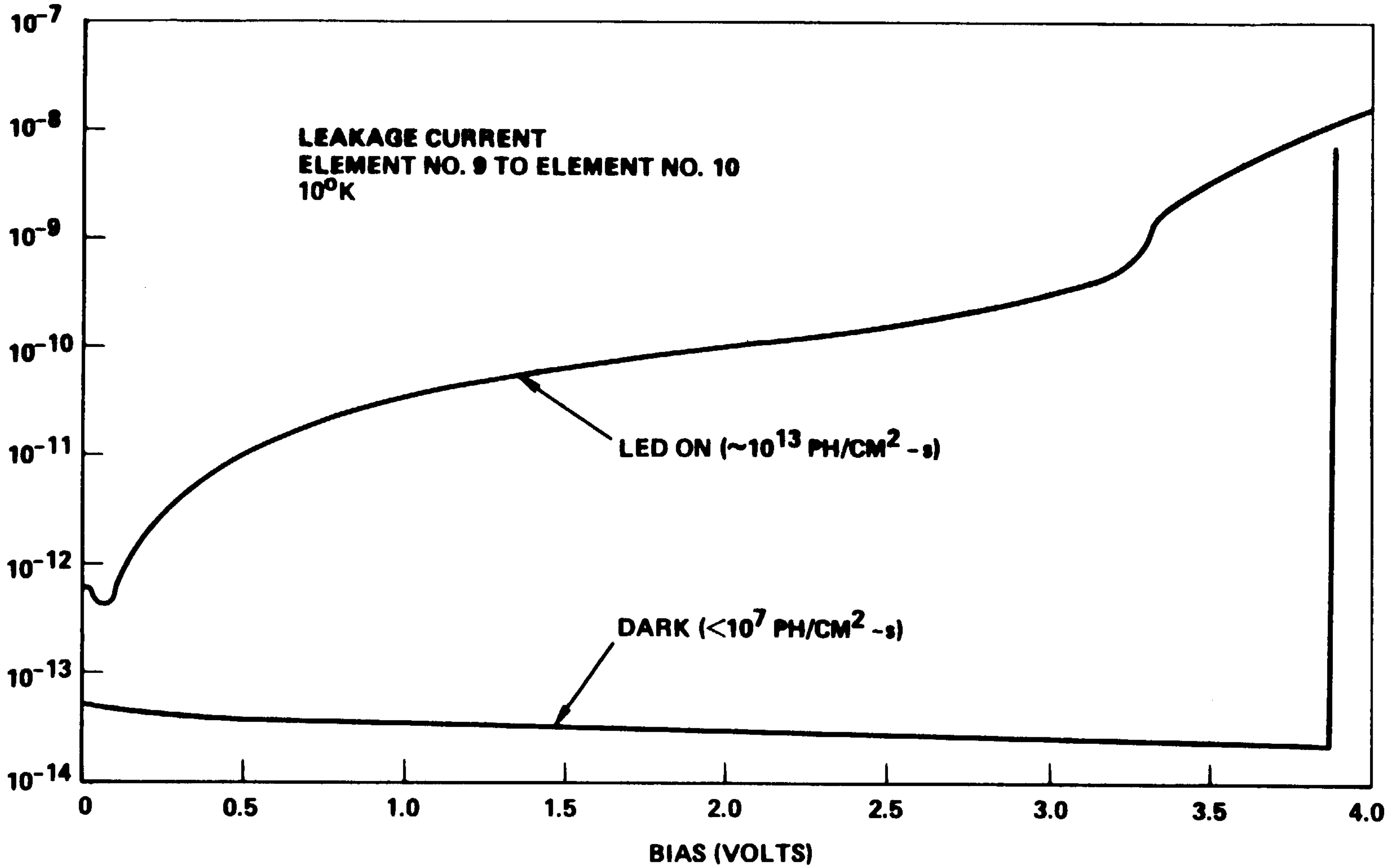

FIGURE 17. DC LEAKAGE CURRENT: ELEMENT #9 TO 10

2.5 Load Resistor Selection

Model 106 resistors were purchased from ELTEC Instruments to be used as load resistors in the array assembly. Resistors were screened at 300, 77, and 4.3°K. Ten resistors were epoxied to ceramic carriers and then attached to the JFET packages. The values of the selected resistors were then measured at 10 and 12°K using biases of 1.0, 0.5, 0.1 and 0.01V. Spot checks were performed at 4.3°K. The test setup is shown in Figure 18. Because of low current levels at 0.01V bias, the measurement system was not accurate at this level, invalidating the load resistor data at 0.01V bias. Load resistor values are listed in Table 1. Three load resistors failed (open circuited) after several thermal cycles to 4.3°K. They were replaced with new calibrated resistors.

Nominal load resistor values are 1.5×10^{11} ohms at 10°K. The measurements show little variation in resistance values with changing bias or temperature.

TABLE 1. LOAD RESISTOR VALUES

Array Element#	T = 10K Bias = 1.0V Resistance (Ω)	T = 10K Bias = 0.5V Resistance (Ω)	T = 10K Bias = 0.1V Resistance (Ω)
1	1.79×10^{11}	1.85×10^{11}	1.56×10^{11}
2	1.04×10^{11}	1.07×10^{11}	1.06×10^{11}
3	1.57×10^{11}	1.61×10^{11}	1.33×10^{11}
4	1.67×10^{11}	1.77×10^{11}	1.80×10^{11}
5	1.21×10^{11}	1.27×10^{11}	1.20×10^{11}
6	1.07×10^{11}	1.11×10^{11}	1.03×10^{11}
7	1.11×10^{11}	1.12×10^{11}	8.73×10^{10}
8	1.41×10^{11}	1.47×10^{11}	1.43×10^{11}
9	1.38×10^{11}	1.44×10^{11}	1.44×10^{11}
10	1.30×10^{11}	1.37×10^{11}	1.37×10^{11}

Array Element#	T = 12K Bias = 1.0V Resistance (Ω)	T = 12K Bias = 0.5V Resistance (Ω)	T = 12K Bias = 0.1V Resistance (Ω)
1	1.75×10^{11}	1.92×10^{11}	1.59×10^{11}
2	1.03×10^{11}	1.06×10^{11}	1.01×10^{11}
3	1.61×10^{11}	1.67×10^{11}	1.52×10^{11}
4	1.56×10^{11}	1.55×10^{11}	1.32×10^{11}
5			
6			
7	1.16×10^{11}	1.22×10^{11}	1.25×10^{11}
8	1.39×10^{11}	1.42×10^{11}	1.32×10^{11}
9	1.36×10^{11}	1.41×10^{11}	1.33×10^{11}
10	1.26×10^{11}	1.33×10^{11}	1.23×10^{11}

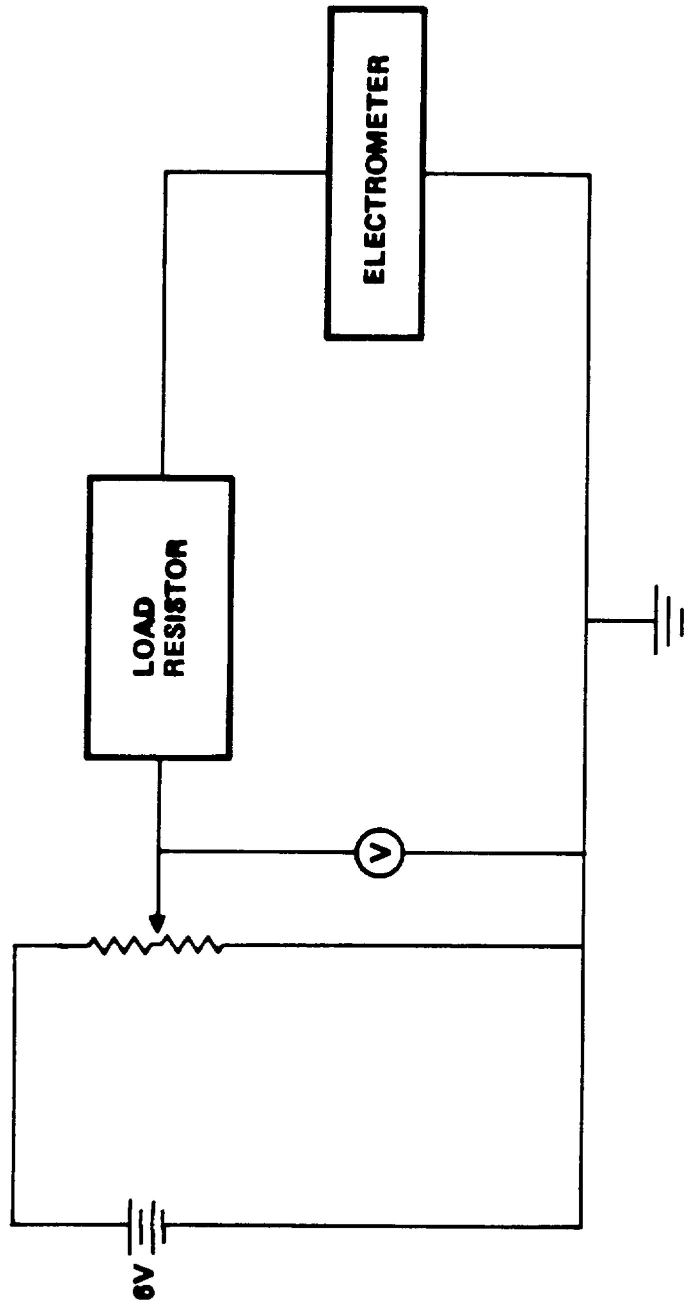

FIGURE 18. LOAD RESISTOR MEASUREMENT SETUP

3.0 BIB DETECTOR ARRAY PERFORMANCE

3.1 Spectral Response

Spectral response data, representative of the processing lot, was supplied by the Naval Ocean Systems Center, San Diego, California. The curves shown in Figures 19 and 20 were obtained using a device from the same wafer as the device delivered under this contract. The data shows the effects of temperature and bias on the BIB detector's spectral response.

3.2 BIB Detector Array Testing

After mounting the preamplifier packages, load resistors, and BIB detector array on the heatsink, ac tests were run at cryogenic temperatures. The tests were performed in the source follower configuration shown in Figure 21. Measurements were made using a 15 micrometer narrow bandpass filter with an IR background flux $Q_B = 1.3 \times 10^9$ ph/cm^2-s. The infrared source used was a 500°K chopped blackbody.

Signal and noise were measured as a function of bias at 10°K for each of the ten array elements. The results are shown in Table 2. Table 3 shows the calculated responsivity and relative D^*. Possible causes for small nonuniformities in these values are uncertainties in load resistor and JFET gate capacitance values.

Signal and noise were also measured as functions of frequency for two array elements at 10°K (Table 4) and as functions of temperature for one array element at 10 Hz (Table 5).

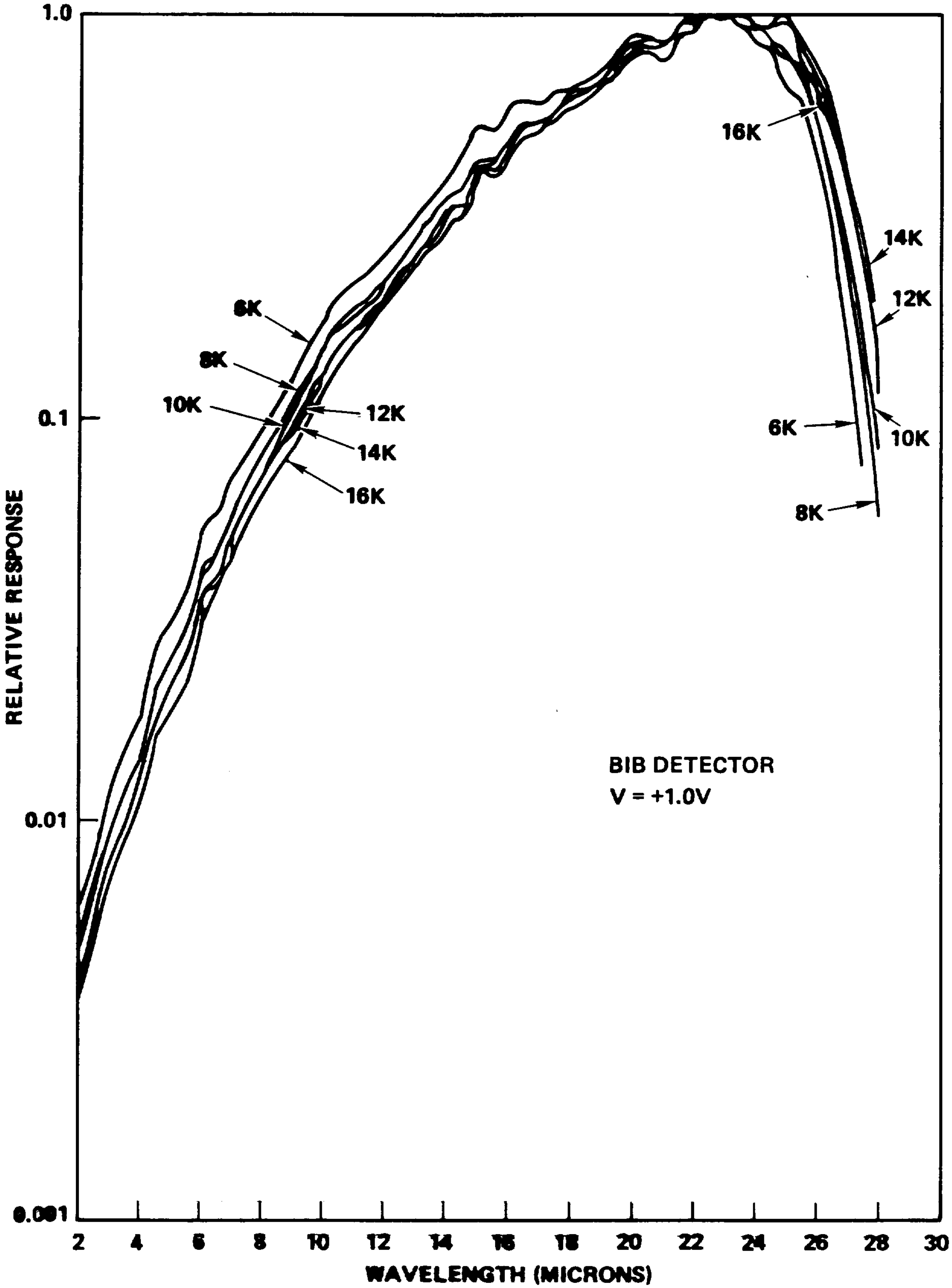

FIGURE 19. SPECTRAL RESPONSE AS A FUNCTION OF TEMPERATURE

SECRECY ORDER
MATERIAL

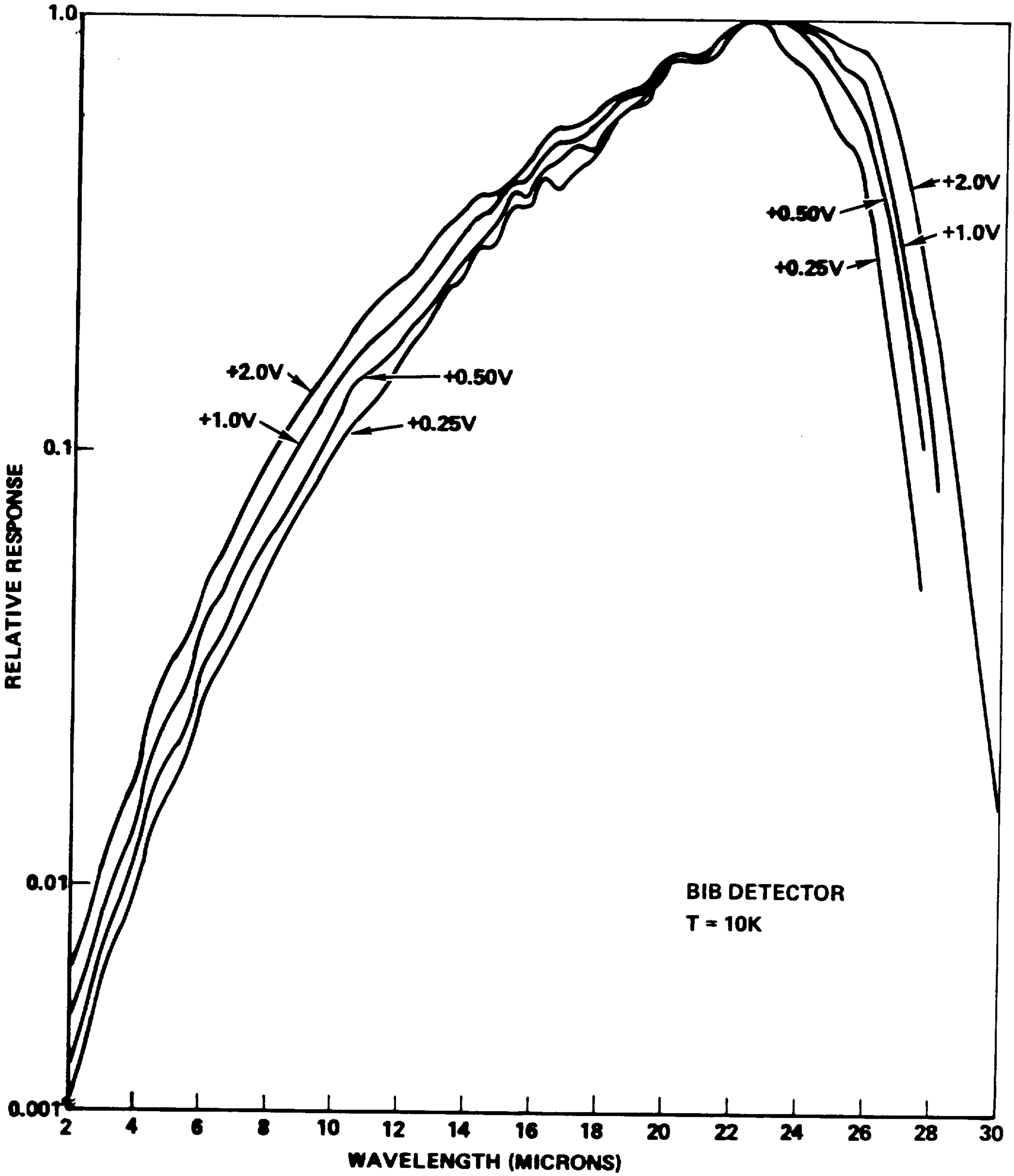

FIGURE 20. SPECTRA RESPONSE AS A FUNCTION OF BIAS

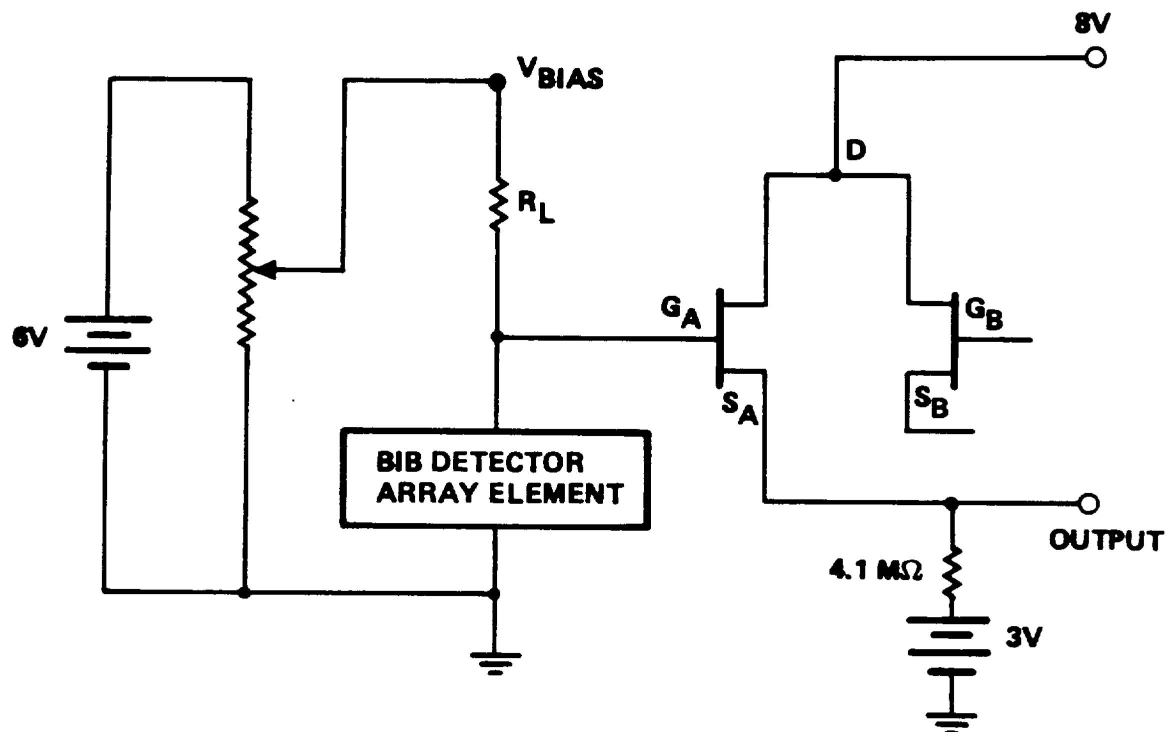

FIGURE 21. AC TEST CONFIGURATION

TABLE 2. SIGNAL AND NOISE vs BIAS

	Element #1		Element #2		Element #3		Element #4		Element #5	
Bias (Volts)	Signal(μV)	Noise(μV)	Signal(μV)	Noise(μV)	Signal(μV)	Noise(μV)	Signal(μV)	Noise(μV)	Signal(μV)	Noise(μV)
0	-		-	.45	-	.7	-	.4	-	.6
0.5	92	.5	54	.5	81	.75	74	.55	53	.6
1.0	125	.8	93	.6	120	.85	115	.65	95	.65
1.5	185	.9	148	.75	175	.95	168	.85	150	.8
2.0	290	1.1	238	1.25	255	1.35	248	1.0	238	1.15
2.5	410	1.6	380	1.8	400	1.6	390	1.6	400	1.7
3.0	670	3.0	660	3.0	635	2.9	610	2.7	670	2.9
3.5	1025	4.8	1050	5.5	975	4.5	975	4.5	1200	5.0

	Element #6		Element #7		Element #8		Element #9		Element #10	
Bias (Volts)	Signal(μV)	Noise(μV)	Signal(μV)	Noise(μV)	Signal(μV)	Noise(μV)	Signal(μV)	Noise(μV)	Signal(μV)	Noise(μV)
0	-	.26	-	.27	-	.26	-	.26	-	.26
0.5	56	.45	71	.4	72	.35	49	.35	75	.38
1.0	105	.5	120	.55	105	.55	86	.45	105	.5
1.5	165	.7	185	.8	160	.75	130	.7	160	.7
2.0	258	1.1	290	1.4	235	1.0	200	.95	240	1.0
2.5	420	2.0	465	2.1	360	1.9	320	1.4	370	1.6
3.0	720	3.2	780	3.5	560	3.0	560	3.0	600	3.0
3.5	1250	6.0	1300	5.5	900	5.5	920	4.5	1000	5.0

Temperature = 10°K

Frequency = 10 Hz

TABLE 3. RESPONSIVITY AND RELATIVE D* vs BIAS

	Element #1		Element #2		Element #3		Element #4		Element #5	
Bias (Volts)	Rel.D*	R (A/W)	Rel.D*	R (A/W)	Rel.D*	R (A/W)	Rel.D*	R (A/W)	Rel.D*	R (A/W)
0.5	48	3.8	28	2.3	28	3.4	35	3.1	23	2.2
1.0	41	5.2	40	3.9	37	5.0	46	4.8	38	4.0
1.5	54	7.7	51	6.2	48	7.3	52	7.0	49	6.3
2.0	69	12.1	49	10.0	49	10.7	65	10.4	54	10.0
2.5	67	17.1	55	15.9	65	16.7	64	16.3	61	16.7
3.0	58	28.0	57	27.6	57	26.5	59	25.5	60	28.0
3.5	56	42.8	50	43.9	56	40.7	56	40.7	63	50.2

	Element #6		Element #7		Element #8		Element #9		Element #10	
Bias (Volts)	Rel.D*	R (A/W)	Rel.D*	R (A/W)	Rel.D*	R (A/W)	Rel.D*	R (A/W)	Rel.D*	R (A/W)
0.5	32	2.3	46	3.0	54	3.0	37	2.1	51	3.1
1.0	55	4.4	57	5.0	50	4.4	50	3.6	55	4.4
1.5	61	6.9	60	7.7	56	6.7	48	5.4	60	6.7
2.0	61	10.8	54	12.1	61	9.8	55	8.4	63	10.0
2.5	55	17.6	58	19.4	49	15.0	60	13.4	60	15.5
3.0	59	30.1	58	32.6	49	23.4	49	23.4	52	25.1
3.5	54	52.3	62	54.4	43	37.6	53	38.4	52	41.8

Temperature = 10°K

Frequency = 10 Hz

TABLE 4. SIGNAL AND NOISE vs FREQUENCY

Element #5

Frequency (Hz)	Signal (μV)	Noise (μV)	Relative D^*	Responsivity (A/W)
2	1125	5.0	59	9.5
5	505	2.0	66	10.6
10	238	1.0	62	10.0
20	110	.6	48	9.2
40	63	.27	61	10.5
80	31	.25	32	10.4
100	24.5	.23	28	10.2
200	10.5	.23	12	8.8

Element #10

Frequency (Hz)	Signal (μV)	Noise (μV)	Relative D^*	Responsivity (A/W)
2	1150	4.5	67	9.7
5	500	1.8	72	10.5
10	245	1.0	64	10.2
20	125	.63	52	10.4
40	61	.3	53	10.2
80	30	.16	49	10.0
100	24	.14	45	10.0
200	10.5	.13	21	8.8

Temperature = 10°K

Bias = 2.0 volts

TABLE 5. SIGNAL AND NOISE vs TEMPERATURE

Temperature (K)	Element #5 Signal (μV)	Element #5 Noise (μV)	Relative D^*	Responsivity (A/W)
4.5	150	.8	49	6.3
6	215	.7	80	9.0
8	250	.95	69	10.4
10	260	1.1	62	10.9
12	230	1.8	33	9.6
13	150	2.5	16	6.3

Frequency = 10 Hz

Bias = 2.0 volts

4.0 CONCLUSIONS

On this program a ten-element silicon BIB detector linear array was selected, mounted on a heat sink with JFETs and calibrated load resistors, tested, and delivered to NASA-Ames Research Center. Because of their high responsivity coupled with good array uniformity, and freedom from performance irregularities, BIB detectors offer significant advantages over conventional extrinsic silicon photoconductive (ESPC) detectors. The data obtained herein confirms some of the advantages and suggest the applicability of BIB detectors for many low background scenarios.

APPENDIX

Data provided by: Infrared Laboratories
1808 East 17th Street
Tucson, Arizona 85719

MODEL JFET 00 FIVE-CHANNEL

General Description

Selected, matched pairs of JFETs mounted in a light tight Au plated Cu enclosure, such that when the enclosure is maintained at LHe temperature, the JFET temperature remains in the operating range 60-80°K. The lowest resonant frequency of the internal structure is >400 Hz, resulting in extremely low microphonic noise and the ability to withstand strong vibration.

Test Data for JFET module #501

S.N. 501	V_s (300) Volt	V_s (77) Volt	V_s (4.2) Volt	V_n (5Hz-80Hz) Nanovolt/$Hz^{1/2}$
Channel 1				
A	1.934	1.597	1.557	6.0
B	1.930	1.595	1.555	5.6
Channel 2				
A	1.936	1.608	1.543	6.7
B	1.935	1.606	1.540	5.7
Channel 3				
A	1.917	1.587	1.544	5.3
B	1.918	1.587	1.545	5.7
Channel 4				
A	1.945	1.612	1.540	8.2
B	1.941	1.609	1.537	5.3
Channel 5				
A	1.936	1.605	1.558	5.2
B	1.931	1.604	1.559	5.2

Data provided by: Infrared Laboratories
1808 East 17th Street
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MODEL JFET 00 FIVE-CHANNEL

General Description

Selected, matched pairs of JFETs mounted in a light tight Au plated Cu enclosure, such that when the enclosure is maintained at LHe temperature, the JFET temperature remains in the operating range 60-80°K. The lowest resonant frequency of the internal structure is >400 Hz, resulting in extremely low microphonic noise and the ability to withstand strong vibration.

Test Data for JFET module #502

S.N. 502	V_s (300) Volt	V_s (77) Volt	V_s (4.2) Volt	V_n (5Hz-80Hz) Nanovolt/$Hz^{1/2}$
Channel 1				
A	1.968	1.689	1.569	5.9
B	1.968	1.688	1.568	6.5
Channel 2				
A	1.960	1.677	1.545	6.9
B	1.959	1.676	1.545	5.4
Channel 3				
A	1.959	1.677	1.548	5.4
B	1.957	1.677	1.547	5.9
Channel 4				
A	1.961	1.682	1.559	5.4
B	1.958	1.677	1.557	5.5
Channel 5				
A	1.947	1.667	1.544	5.5
B	1.944	1.666	1.543	5.9

Data provided by: Infrared Laboratories
1808 East 17th Street
Tucson, Arizona 85719

IRL MODEL J-F 230, CRYOGENIC JFET MODULE

J-FET TYPE: J230, selected, matched pair

APPLICATION: LHe cooled preamp for low background infrared detectors

GENERAL DESCRIPTION:

Photon sealed, Au plated Cu enclosure with dacron fiber & Manganin wire thermal isolation permit 60 - 77K JFET operation at 200 microwatt power dissipation. Space flight qualified to 400 g above 400 Hz resonant frequency. Selfheated, automatic start-up at 4K. Johnson noise limited with 1E10 ohm feedback resistor (R_F).

SPECIFICATIONS:

Po	- 200 to 300 microwatt total
Supply	- $\pm$ 9V to $\pm$ 15V
Input Cap.	- 4 pf
Shorted input noise	- 5 to 10 nanovolt/$Hz^{1/2}$ at 80 Hz
Transconductance	- 0.2 ma/volt
Max. Recommended R_F	- 5E10 ohms
d.c. offset	- < 15 mv
Gate current	- < 5×10^{-16} amp
Weight:	- 4.0 gm.
Case Dimensions:	- 6.0 x 6.5 x 34 mm

Data provided by: Infrared Laboratories
1808 East 17th Street
Tucson, Arizona 85719

MODEL JFET 00

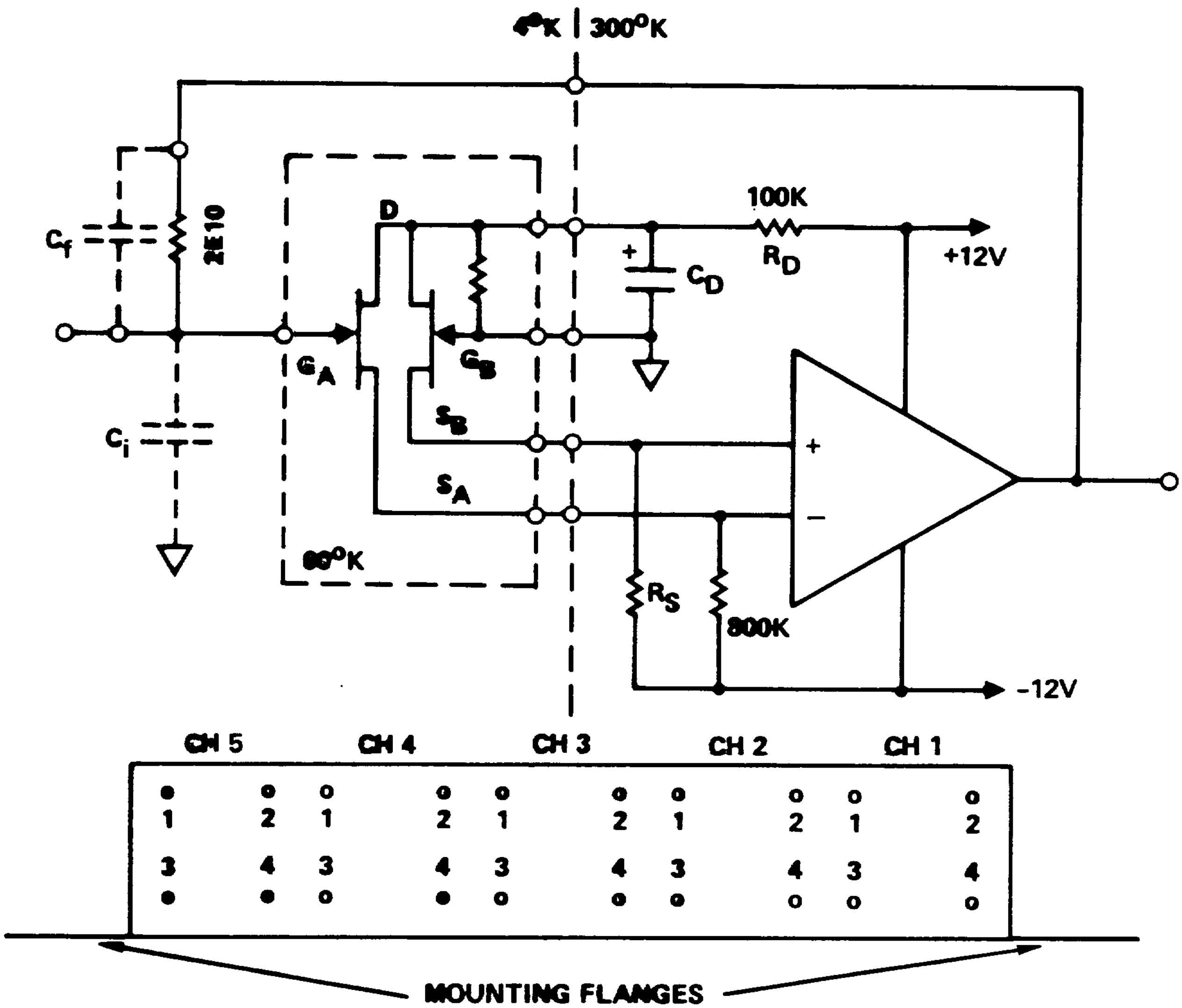
CAUTION:

The small weep holes (0.0135") on the sides next to the flanges should not be inadvertently sealed as this allows evacuation of the unit.

Care should by taken to insure that R_s on the inactive side is not shorted. This will cause a large current to flow and melt the .001" Manganin wire. The JFET itself is unharmed.

Do not bend the leads sharply at the case as they are copper and can be snapped off.

DRAWING PROVIDED BY: INFRARED LABORATORIES
1808 EAST 17th STREET
TUCSON, ARIZONA 85719



1 – DRAINS
2 – SOURCE B
3 – SOURCE A
4 – GATE B

GATE A ON OPPOSITE END

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15. Supplementary Notes

Technical Monitor: Dr. Craig R. McCreight, Ames Research Center, M.S. 244-7, Moffett Field, CA 94035. 415-965-6549; FTS 448-6549

16. Abstract

The report describes a ten-element infrared array made of arsenic-doped silicon blocked-impurity-band (BIB) detectors. The BIB concept, the array mounting scheme, the method of array selection, and characteristics of the JFET preamplifiers are described. Performance data, which include responsivity, noise, uniformity, and spectral response, are included.

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